Drone Systems and Applications

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New topic horizons for drone systems and applications

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Summary

This journal (Drone Systems and Applications; DSA) conducted a targeted "horizon scan" during 2022 within our team of editors and associate editors. We asked—*Which research areas currently under-represented in Drone Systems and Applications would you like to see more heavily represented in the future?* The process highlighted five areas of interest and potential growth:

- Drones in the geosciences
- Aquatic drones
- Ground drones
- Drones within calibration/validation experiments
- Drones and computer vision

Over the past two years (2020–22), the journal has published over 50 papers with a strong leaning towards aerial drones for ecology and also with an engineering focus. DSA is keen to receive new submissions addressing the five highlighted areas, which lie firmly within the aims and scope of the journal. Further to the horizon scan, we propose two special collections for the coming year—one addressing drone applications (*drones in geoscience applications*) and a second addressing drone systems (*aquatic drone systems*). We would like to hear from scientists and practitioners in these fields as both contributors and (or) collection editors.

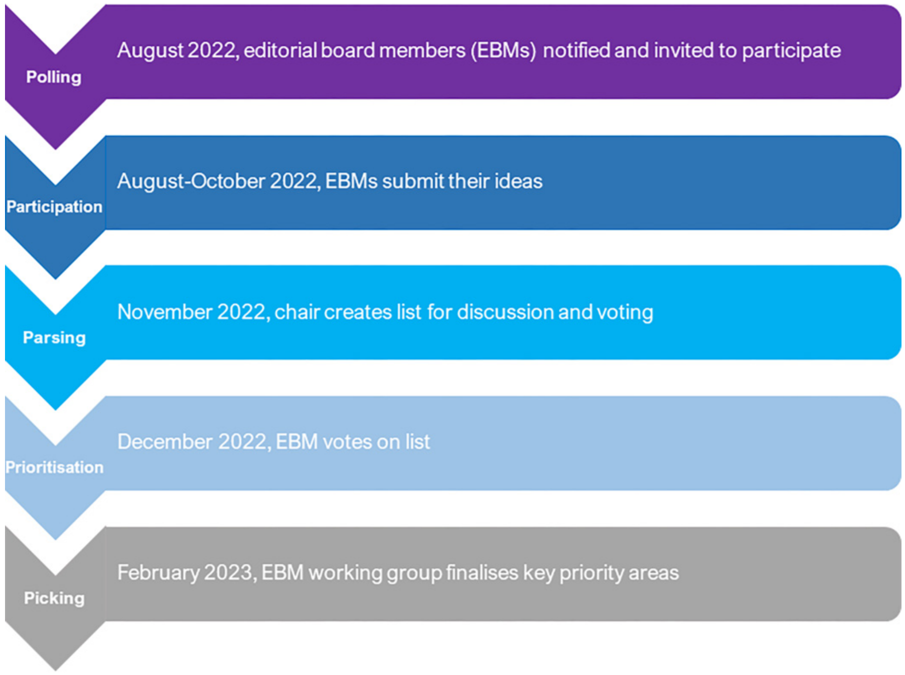
1. Introduction

Horizon scanning is a widely used toolkit that is primarily used for proactive identification of opportunities and threats to enable solutions-based thinking. It can also be used to identify areas where there are gaps in knowledge or for highlighting areas in need of urgent scientific attention. Inspired by Sutherland et al.'s long-running "horizon scan" process in conservation biology (e.g., Sutherland et al. 2023), we employed a light-touch horizon scan approach within our editorial board. In recognising that the aims and scope of our journal are very broad—covering robotic vehicles on the land, sea, air, and other planets, we wanted to use the horizon scan to identify under-represented research areas within these broad themes. The end goal was to target researchers in those areas to attract them to DSA for publication of their work and also to use the outcome to choose two topics as subjects for special collections. This short paper explains the process and highlights the outcomes of that process.

2. Approach

Thirty-two editorial board members from nine countries were polled in August 2022—asking the narrow question: "Which research areas currently under-represented in DSA would you like to see more heavily represented in the future?" A Google form was circulated that invited participants to input a short descriptor and a more detailed narrative, with evidence if available. All submissions to this process were anonymous. Participants were given until early October (over 1 month) to participate and reminded of the process on a couple of occasions by email. Eleven original ideas were shared. The suggestions were collated and summarised by the chair of the horizon scan working group, and similar topics were grouped. There was some duplication of ideas, resulting in a final list of eight topics. In December 2022, during the editorial board meeting, the chair presented an unbiased summary of these eight topics, and all members of the editorial board were asked to vote for their top three preferences

Fig. 1. Major milestones in the horizon scan process.



using an online mentimeter poll. This resulted in five clear top-voted themes. A working group (above-named authors) was convened to conclude the process by picking the short-list of topics from those identified and voted on. We collaborated to write this piece summarising the top-voted topics. Figure 1 highlights the major steps in the workflow.

3. Results

The top five themes (following prioritisation and voting—Fig. 1) were as follows.

Drones in the geosciences—the journal has long published a substantial share of quality content related to applications of drones in environmental sciences, perhaps most notably wildlife-related applications, but also other prominent areas such as in forestry, water resource sciences, landscape and habitat monitoring, and ecology more broadly. A bibliometric analysis on the Web of Science conducted by Chabot (2018) found that while environmental sciences, wildlife, and ecology were indeed among the fastest-growing areas of drone applications, an even larger and faster-growing area of application that has been comparatively under-represented in the journal are the geosciences, specifically geology, geomorphology, geophysics, physical geography, and the like. This suggests that there is some untapped potential for the journal to attract a larger share of content from these areas. Central to many geoscientific endeavours and field experiments is the need to capture data describing "outcrop, landform or other surface topography" (Carrivick et al. 2013). Drones equipped with cameras can provide both a rapid means of evaluating site layouts, while structure-from-motion photogrammetry or even drone lidar can be used to measure topographic information for understanding size, shape, orientation, and landform morphology. Using more diverse sensors on board airborne or terrestrial drones, including magnetometers or ground-penetrating radars, can reveal new insights to both surface and sub-surface processes (Niedzielski 2018). Advances in processing have also been made in recent years that have allowed consideration of such things as point-based uncertainties in photogrammetry (e.g., James et al. 2017), allowing for more robust time-series monitoring of geomorphological or geological phenomena from drone-captured data. Of great relevance to our journal is that geoscience drones may be used to explore both surface and subsurface processes, so this is not just an area for exploitation of aerial drones. Space drones could explore surfaces or atmospheres of other planets, earthworm-like drones (Das et al. 2023; Fig. 2) could capture information about soils and edaphic processes, while underwater or under-ice robotic vehicles could send back information about deep ocean systems or processes under ice sheets (e.g., Meister et al. 2019; Schmidt et al. 2023).

Aquatic drones—this is a broad field and in our previous editorial (Chabot et al. 2022), we defined two types of drones in this category: underwater drones and water-surface drones (Fig. 3). In underwater realms, remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) have been widely used over the past few decades (Bogue 2015), servicing heavily the oceanographic science community and the offshore oil and gas industry. The main difference between ROVs and AUVs is that ROVs are piloted from the surface via tethered cabling, whereas AUVs navigate themselves underwater using dead reckoning aided by external readings such as terrain sensing (e.g., using acoustic methods) or tracking their speed and depth. Other types of AUVs deliberately drift with ocean currents. AUVs are preferred over ROVs in

Fig. 2. A new peristaltic earthworm robot that could be useful for subsurface edaphic exploration (reproduced with permission from Duilio Farina and Riddhi Das from the Istituto Italiano di Tecnologia (see also Das et al. 2023)).

situations where surface vessels can hinder operations—e.g., in politically sensitive areas, those where piracy is prevalent, or places that are hard to reach or inhospitable. An important sub-class of AUVs is Argo floats, which ascend and descend through the water column using zigzag volumetric motions, where buoyancy is balanced via water intake or release (Wong et al. 2020). This international programme operates 4000 Argo floats across global oceans (Fig. 4), with the quantity maintained as floats fail or are removed. They provide information about temperature, salinity, and pressure as a core mission goal (of ocean physics), but the relatively recent development of bio-Argo floats is enabling the collection of biogeochemically relevant parameters (e.g., Su et al. 2022). Innovations in sub-surface glider design have also produced machines that can move and soar underwater just like airborne gliders, and these systems are delivering improvements in the accuracy of delivery to the seafloor, opening up new opportunities for mapping and sampling among other applications (Reed et al. 2011). Aside from geotechnical, oil/gas and oceanic applications, there are marine biological applications for subsurface drones too—e.g., gliders have also been used to monitor cetaceans (Klinck et al. 2012) or to follow frontal systems. On the ocean water surface, there are various types of autonomous vehicles (also known as autonomous surface vehicles (ASVs) or uncrewed surface vehicles (USVs)), which may be motorised, wind-powered, or wave-powered. Both can be fitted with sensors to measure surface and subsurface physical characteristics. Wind-powered drones can operate in various modes, from lower endurance near-shore missions for short-duration exploration to ocean-going long-endurance machines equipped with radars and sub-surface profilers. Of note is that a solar-powered motorised USV completed a transatlantic crossing recently, evidencing the long-endurance capabilities of such craft (Ramirez 2022). Scientific experiments with data from these drones have included biogeochemical flux experiments (Zhang et al. 2019), ecological surveys (Mordy et al. 2017), marine fauna monitoring (Verfuss et al. 2019), and marine acoustics (Bingham et al. 2012)—but this is by no means an exhaustive list of examples. We have predominantly focused on ocean/marine research in describing these innovative robotic platforms, but of course there are other aquatic environments that can be monitored with similar approaches. While there seems to be less work in freshwater science, there is still great potential for using ROVs, AUVs, and ASVs/USVs for surveying the surface dynamics and volumetric characteristics of rivers and lakes (e.g., Rogowski et al. 2014) as well as inshore coastal waters like harbours, with associated understanding that the risks of deployment in these environments are different from open-ocean deployments (Snyder et al. 2004).

Calibration/validation—in many fields of environmental research, there is a well-documented "scale mismatch" between *in situ* observations and remote sensing measurements captured by Earth observation satellites. The former are classically used to understand processes at fine grain, while the latter can be used to extrapolate local observations to broader spatial extents and (or) monitor environmental dynamics through time. Bridging this scale mismatch is challenging since it can require all three of the spatial, temporal, and spectral dimensions to be linked. The agile capacity of drones to carry a range of sensors measuring at ultra-fine (from sub-centimetre to decimetre, typically) spatial resolution, at user-defined time-steps, offers a unique capability to bridge that scaling gap (Whitehead and Hugenholtz 2014). Indeed, there are some studies where drone data have been used for calibration or validation of satellite remote sensing data or products—e.g., in burn severity mapping (Fraser et al. 2017) and for scaling spectroscopic measurements (Naethe et al. 2023). There are further works describing intercomparison of data from field, to drone, to satellite—e.g., vegetation indices (Fawcett et al. 2020) and in agricultural applications (Messina et al. 2020). Beyond scientific applications, there is already evidence that major space agencies are exploring the use of drones within calibration/validation operations—e.g., a recent exercise to test approaches for Landsat calibration/validation (USGS 2023). Furthermore, there are other studies that show that the drone scale captures phenomena that are otherwise not measurable from satellite data with coarser spatial resolution (Assmann et al. 2020). Of course, the integration of drone-captured data into calibration/validation workflows for major spaceborne missions must address key issues around data reproducibility, interoperability, and intercalibration that until now—Alvarez-Vanhard et al. (2021) argue—has "strongly limited the nature of exploitation of the synergies" between drones and satellite products.

Ground drones—also known as unoccupied ground vehicles (UGVs) or rovers, this family of drones is a rapidly evolving area of technology and research. Ground drones may take various forms, including wheeled, tracked, legged, and amphibious hovercrafts. Their ability to navigate complex and hazardous terrestrial environments and perform tasks autonomously offers significant advantages over human operators in various applications. A promising research direction for ground drones is multi-robot collaboration. In this approach, multiple drones work together to perform

Fig. 3. The diversity of "aquatic drones": (*a*) submersible vehicle MARUM-QUEST, (*b*) saildrone, (*c*) autonomous surface wave glider, and (*d*) subsurface Argo float (image credit https://argo.ucsd.edu). Images (*a*–*c*) shared under creative commons licences.

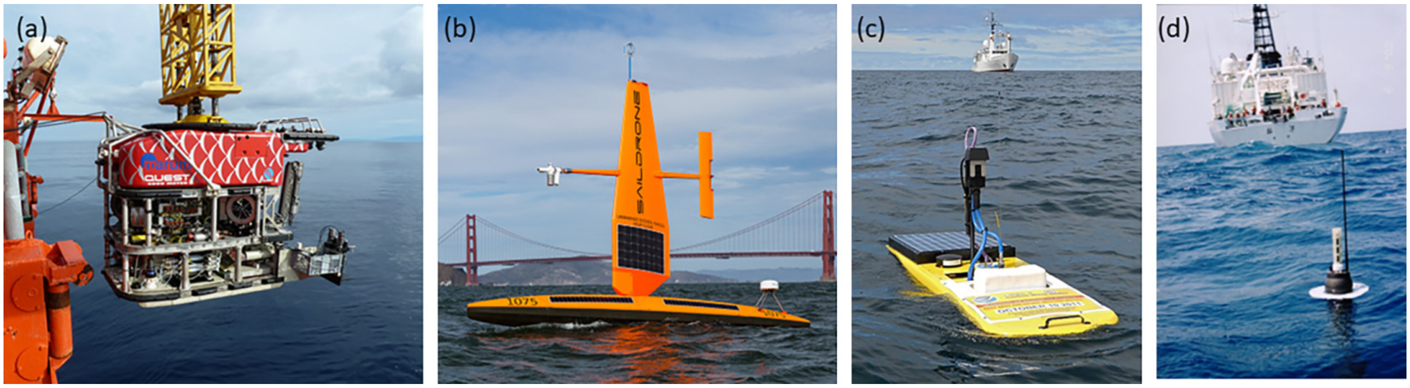
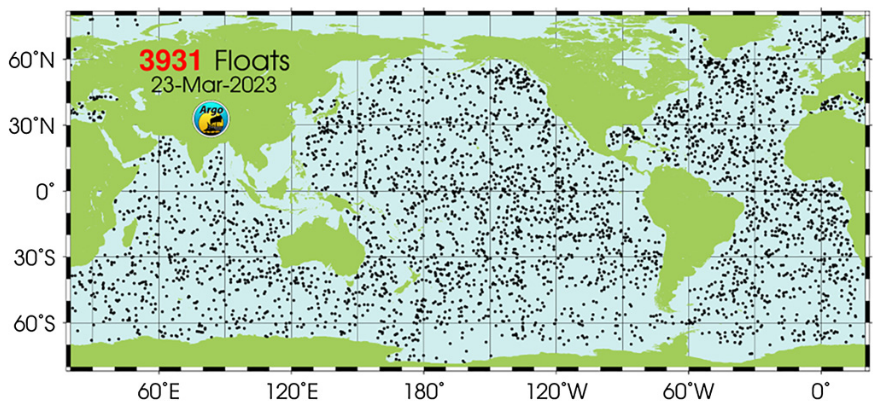


Fig. 4. Argo float distribution in the global ocean, March 2023 (credit: https://argo.ucsd.edu/about/status/)



complex tasks that would be difficult or impossible for a single drone. This approach requires advanced communication and coordination algorithms that enable drones to share information, collaborate, and adapt in real time. For example, multiple drones could be used for search-and-rescue missions, where each drone is assigned a specific area to explore, and the information is shared among all drones to optimise the search process. The recent *Darpa Subterranean Challenge* asked teams of drones to rapidly map, navigate, and search in underground disaster scenarios. Many theoretical and systems papers were published as an output of the challenge (e.g., Tranzatto et al. 2022). Another important application of ground drones is precision agriculture. In recent work, coordinated fleets of aerial drones identify areas for treatment before ground robots are sent on autonomous missions to deliver an intervention (e.g., pest control and fertiliser or water application (Gonzalez-de Santos et al. 2017)). In fact, the pairing of autonomous ground rovers and aerial drones seems attractive in other settings too—concepts have been tested for this mode of operation in underground mines, where the "canary" (aerial drone) scouts the geospatial environment for the "badger" (ground drone) to explore (Watson et al. n.d.). Ground drones have also been designed to support aerial drones—e.g., for providing level areas for landing and charging (Quaglia et al. 2019). Operating individually, there are ground drone prototypes designed for pollution monitoring—e.g., fitted with gas sensors to survey areas too dangerous or unpleasant for human work (Carpentiero et al. 2017). Furthermore, research is actively being conducted with rovers on Mars and other planets (Azkarate et al. 2022). We know from Martian experiments that much can be learned about sedimentary and geological processes from such machines (Lakdawalla 2018). Yet, we are reminded by work of social scientists like Janet Vertesi that the human–machine interface (when programming rovers to perform manoeuvres on remote planetary surfaces) is highly complex (Vertesi 2012). The development of more advanced autonomous control systems is key to the future of ground drones. Advances in machine learning, computer vision, and artificial intelligence are enabling drones to perform increasingly complex tasks autonomously. The development of advanced navigation, obstacle avoidance, and object recognition algorithms will enable ground drones to operate more effectively and safely in real-world situations.

Drones and computer vision—practitioners across numerous fields have hailed the emergence of drones as convenient and boundlessly productive new tools that place the ability to collect on-demand imagery directly into their hands. However, the mushrooming production of vast amounts of fine-resolution drone-acquired imagery is a double-edged sword: it is a major challenge to keep up with the need to analyse all this imagery to extract actionable information. Therefore, to truly realise the potential of drones as turnkey remote sensing platforms, equivalently convenient, efficient, and versatile image analysis solutions are required to match. Computer vision-based algorithms have been widely exploited within drone data processing to fit this need. The most obvious leveraging of computer vision within drone science has occurred on the mapping side—i.e., in basic "stitching" of overlapping images using structure-from-motion photogrammetry approaches, which can also deliver volumetric point cloud information in areas of high image overlap. Such approaches are now used routinely across various fields, e.g., fluvial (Carrivick and Smith 2019), coastal (Casella et al. 2017), ecological (Cunliffe et al. 2016), morphometric (Burnett et al. 2019), glacial (Śledź et al. 2021), and forestry (Iglhaut et al. 2019), among others. Beyond generating basic products (orthomosaic and point cloud), computer vision approaches can be used to deliver deeper insights from drone data—with deep learning approaches having three main purposes: scene classification, object detection, and semantic segmentation (Osco et al. 2021). For example, Koger et al. (2023) describe how deep learning approaches can be applied to drone-captured videographic data to understand not just the location and body posture of animals but also the volumetric ecological setting in which they are located. However, it is not just on the remote sensing side that computer vision plays a role in drone science. From a robotics perspective, drones have been hailed for their ability to perform a multiplicity of dull, dirty, and dangerous tasks, replacing humans as well as accessing and navigating places that humans physically cannot. The need for highly precise and quick-reaction control and navigation of drones in such places in combination with remote control challenges requires novel computational solutions. Real-time analysis of the immediate environments in which drones operate has leveraged information flows derived from computer vision. For example, optical flow algorithms (mimicking insect strategies for navigation) have been trialled so as to sense a drone's immediate surroundings and navigate through challenging environments, avoiding obstacles (Conroy et al. 2009; McGuire et al. 2017). Despite major advancements in the past decade, real-time optical flow-guided autonomous navigation remains a research challenge because accurately discriminating distance from velocity has uncertainties in the "highly important flight direction" (de Croon et al. 2021). Nevertheless, computer vision-based optical flow remains an area of intense attention because of the potential capability to deliver precise adjustments to speed and trajectory to avoid collisions in GNSS-denied environments and with reliance on relatively simple lightweight sensors.

4. A retrospective—trends in the past three years of DSA issues

Reflecting on the five topics highlighted as being of interest in the horizon scan, we also looked back through the journal's past three years (2020–2022, inclusive) of issues to determine the spread of papers relative to key topic areas. Papers were classified according to the "studied environment," "topic," and "operational environment." Figures 5–7 provide the results of this process. For categories labelled "All" under studied environment/operational environment, this refers to manuscripts that dealt with generic issues such as cyber security for all drone types/conditions, ethics, autonomous amphibious unpiloted aerial vehicles, and defence/disaster relief in any environment. It is clear that there has been a very strong tendency towards publications involving aerial drones, with 86% of the publications over the 2020–22 period having this focus (Fig. 5). In terms of "topic," there has been a dominant focus on engineering, ecology, and control/safety aspects, with topics such as geoscience, archaeology, agriculture, and ethics comparatively under-represented (Fig. 6). Finally, "studied environments" show a slightly greater diversity, yet we note a relatively smaller number of papers using drones to explore fluvial, desert, mountain, agriculture, and wetland systems (Fig. 7).

Fig. 5. Manuscript spread relative to "operational environment" for the period 2020–2022.

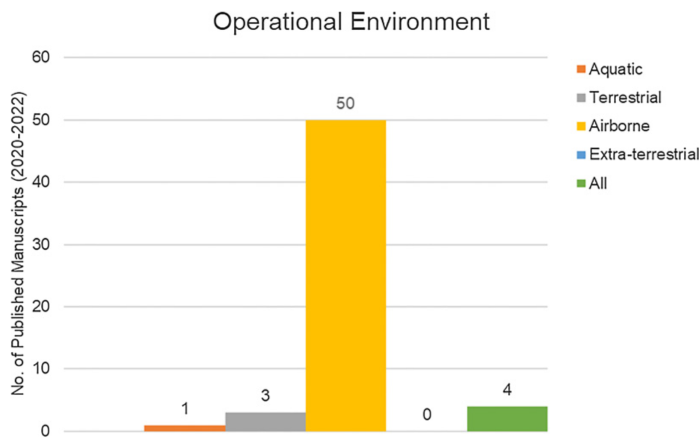


Fig. 6. Manuscript spread relative to "topic" for the period 2020–2022.

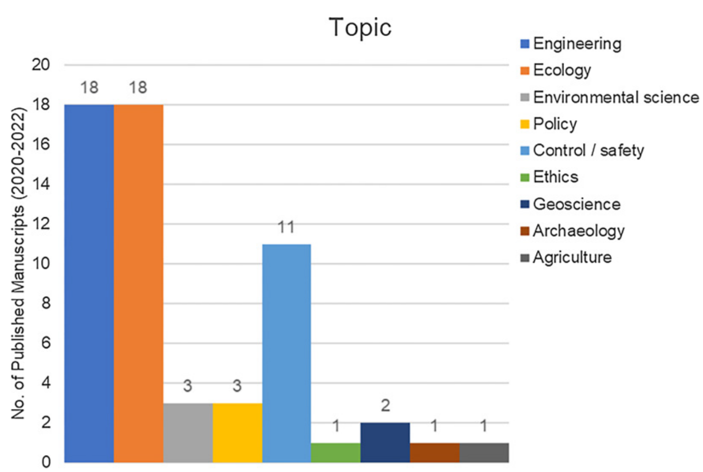
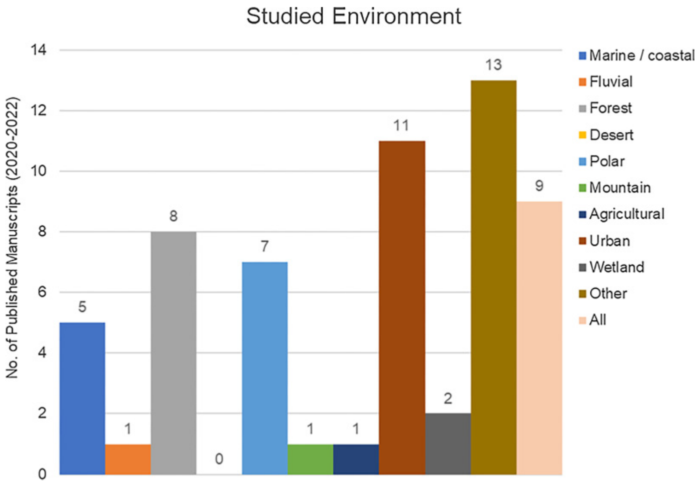


Fig. 7. Manuscript spread relative to "studied environment" for the period 2020–2022.



5. Conclusion

Given the comparative lack of geoscience applications evident in the past three years of DSA issues, we have chosen to select this as a key topic where we would like to grow the journal. We are therefore proposing to host a special collection on the broad topic of "drones in geoscience applications." Given that our journal is not just about applications but also about drone "systems," we have selected aquatic drones as a second, system-focused topic—this is a gap in our back catalogue of published papers and will become a second collection, shortly to be advertised. If you work in either of these fields and would like to join our team of associate editors, please make contact with the editorial team. In conclusion, we are keen to receive submissions on any topic related to all types of robotic vehicles, but we use this editorial to highlight the major "gaps" in our field of published work and to actively encourage those people working in these sectors to submit quality articles to us.

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